CHAPTER 4 Review

REFLECTING ON CHAPTER 4

- Newton expressed his second law in terms of momentum: $\vec{F} = \frac{\Delta \vec{p}}{\Delta t}$.
- Rearrangement of Newton's form of the second law yields the quantities of impulse, $\vec{F}\Delta t$, and a change in momentum, $\Delta \vec{p}$, and shows that impulse is equal to the change in momentum: $\vec{F}\Delta t = \Delta \vec{p}$. This expression is called the "impulse-momentum theorem."
- Momentum is mass times velocity $\vec{p} = m\vec{v}$.
- The concept of impulse plays a significant role in the design of safety systems. By extending the time, Δt, of a collision, you can reduce the amount of force, $\vec{F}$, exerted.
- By applying Newton's third law, you can show that momentum is conserved in a collision.
- The momentum of an isolated system is conserved.
- Recoil is the interaction of two objects that are in contact with each other and exert a force on each other. Momentum is conserved during recoil.
- Kinetic energy is conserved in elastic collisions.
- Kinetic energy is *not* conserved in inelastic collisions.

Knowledge/Understanding

1. Write Newton's second law in terms of momentum. Show how this expression of Newton's law leads to the definition of impulse and to the impulse-momentum theorem.
2. Give an example of a situation in which it is easier to measure data that you can use to calculate a change in momentum than it is to determine forces and time intervals.
3. In many professional auto races, stacks of old tires are placed in front of walls that are close to turns in the racetrack. Explain in detail, using the concept of impulse, why the tires are stacked there.
4. Define "internal force" and "external force" and explain how these terms relate to the law of conservation of momentum.
5. At the instant after a car crash, the force of friction acts on the cars, causing a change in their momentum. Explain how you can apply the law of conservation of momentum to car crashes.
6. When two objects recoil, they start at rest and then push against each other and begin to move. Initially, since their velocities are zero, they have no momentum. When they begin to move, they have momentum. Explain how momentum can be conserved during recoil, when the objects start with no momentum and then acquire momentum.
7. An object that is moving in a circle has angular momentum. Explain why the amount of angular momentum depends on the object's distance from the centre of rotation.
8. Assume that you are provided with data for a collision between two masses that undergo a collision. Describe, step by step, how you would determine whether the collision was elastic or inelastic.
9. Under what conditions is a collision *completely inelastic*?
10. The equations $v_1' = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) v_1$ and $v_2' = \left(\frac{2m_1}{m_1 + m_2}\right) v_1$ were developed for perfectly elastic head-on collisions between two masses, when mass 1 was moving and mass 2 was stationary before the collision. Use these equations to show that, after the collision, the first mass will come to a complete stop and the second mass will move away with a velocity identical to the original velocity of the first mass.

11. Explain how a forensic expert can determine the velocity of a bullet by using a ballistic pendulum.

Inquiry

12. The International Tennis Federation (ITF) approaches you, a physics student, complaining that too many games in tournaments are being won on the strength of either player's serve. They ask you to examine ways to slow down the serve and thus make the game more interesting to watch. Devise a series of experiments to test the ball, the type of racquet used, and the surface of the courts, from which you could make recommendations to the ITF about how to improve the game of tennis.
13. Design a small wooden cart, with several raw eggs as passengers. Incorporate elements into your design to ensure that the passengers suffer no injury if the cart was involved in a collision while travelling at 5.0 m/s. If possible, test your design.
14. Design and carry out an experiment in which an object initially had gravitational potential energy that is then converted into kinetic energy. The object then collides with another object that is stationary. Include in your design a method for testing whether mechanical energy is conserved in the first part of the experiment. If possible, test your design.

Communication

15. A car and a bicycle are travelling with the same velocity. Which vehicle has greater momentum? Explain your reasoning.
16. It is a calm day on a lake and you and a friend are on a sailboat. Your friend suggests attaching a fan to the sailboat and blowing air into the sails to propel the sailboat ahead. Explain whether this would work.
17. Imagine you are standing, at rest, in the middle of a pond on *perfectly frictionless* ice. Explain what will happen when you try to walk back to shore. Describe a possible method that you could use to start moving. Would this method allow you to reach shore? Explain.
18. You and a friend arrive at the scene of a car crash. The cars were both severely mangled. Your friend is appalled at the damage to the cars and says that cars ought to be made to be sturdier. Explain to your friend why this reaction to the crash is unwarranted.
19. Start with expressions that apply the impulse-momentum theorem to two objects and use Newton's third law to derive the conservation of momentum for a collision between the two objects. Explain and justify every substitution and mathematical step in detail.
20. Write the units for impulse and for momentum. Show that these combinations of units are equivalent and explain your reasoning in detail.
21. Movie stunt people can fall from great heights and land safely on giant air bags. Using the principles of conservation of momentum and impulse, explain how this is possible.
22. Why is a "follow-through" important in sports in, for example, hitting, kicking, or throwing a ball?
23. A boy jumps from a boat onto a dock. Explain why he would have to jump with more energy than he would need if he was to jump the same distance from one dock to another.
24. In soccer, goalkeepers need to jump slightly forward to avoid being knocked into the goal by a fast-moving soccer ball as they jump up to catch it. If the ball and goalkeeper are momentarily at rest after the catch, what must have been the relative momenta of the goalkeeper and ball just before the catch?

Making Connections

25. Many automobiles are now equipped with air bags that are designed to prevent injuries to passengers if the vehicle is involved in a collision. Research the properties of air bags. In terms of impulse, how do they work? How quickly do they inflate? Do they remain inflated? What force do they exert on the driver or passenger? What are the safety concerns of using air bags?

26. A patient lies flat on a table that is supported by air bearings so that it is, effectively, a frictionless platform. As the patient lies there, the table moves slightly, due to the pulsating motion of the blood from her heart. By examining the subtle motion of the table, a ballistocardiograph is obtained, which is used to diagnose certain potential deficiencies of the patient's heart. Research the details of how this device works and the information that can be obtained from the data.

27. Particle physicists investigate the properties of elementary particles by examining the tracks these particles make during collisions in "bubble chambers." Examine some bubble chamber photographs (check the Internet) and research the information that can be obtained. Include a discussion of how the law of conservation of linear momentum is applied.

Problems for Understanding

28. Determine the momentum of a 5.0 kg bowling ball rolling with a velocity of 3.5 m/s[N] toward a set of bowling pins.

29. What is the mass of a car that is travelling with a velocity of 28 m/s[W] and a momentum of 4.2×10^4 kg · m/s[W]?

30. The momentum of a 55.0 kg in-line skater is 66.0 kg m/s[S]. What is his velocity?

31. How fast would a 5.0×10^{-3} kg golf ball have to travel to have the same momentum as a 5.0 kg bowling ball that is rolling at 6.0 m/s[forward]?

32. Calculate the impulse for the following interactions.
    (a) A person knocks at the door with an average force of 9.1 N[E] over a time interval of 2.5×10^{-3} s.
    (b) A wooden mallet strikes a large iron gong with an average force of 4.2 N[S] over a time interval of 8.6×10^{-3} s.

33. A volleyball player spikes the ball with an impulse of 8.8 kg · m/s over a duration of 2.3×10^{-3} s. What was the average applied force?

34. If a tennis racquet exerts an average force of 55 N and an impulse of 2.0 N · s on a tennis ball, what is the duration of the contact?

35. (a) What is the impulse of a 0.300 kg hockey puck slapshot that strikes the goal post at a velocity of 44 m/s[N] and rebounds straight back with a velocity of 9.2 m/s[S]?
    (b) If the average force of the interaction was -2.5×10^3 N, what was the duration of the interaction?

36. A 2.5 kg curling stone is moving down the ice at 3.5 m/s[W]. What force would be needed to stop the stone in a time of 3.5×10^{-4} s?

37. At an automobile test facility, a car with a 75.0 kg crash-test dummy is travelling 28 m/s[forward] when it hits a wall. Calculate the force that the seat belt exerts on the dummy on impact. Assume that the car and dummy travel about 1.0 m as the car comes to rest and that the acceleration is constant during the crash.

38. A 0.0120 kg bullet is fired horizontally into a stationary 5.00 kg block of wood and becomes embedded in the wood. After the impact, the block and bullet begin to move with an initial velocity of 0.320 m/s[E]. What was the velocity of the bullet just before it hit the wood?

39. A 48.0 kg skateboarder kicks his 7.0 kg board ahead with a velocity of 2.6 m/s[E]. If he runs with a velocity of 3.2 m/s[E] and jumps onto the skateboard, what is the velocity of the skateboard and skateboarder immediately after he jumps on the board?

40. Astrid, who has a mass of 37.0 kg, steps off a stationary 8.0 kg toboggan onto the snow. If her forward velocity is 0.50 m/s, what is the recoil velocity of the toboggan? (Assume that the snow is level and the friction is negligible.)

41. A 60.0 t submarine, initially travelling forward at 1.5 m/s, fires a 5.0×10^2 kg torpedo straight ahead with a velocity of 21 m/s in relation to the submarine. What is the velocity of the submarine immediately after it fires the torpedo?

42. Suppose that a 75.0 kg goalkeeper catches a 0.40 kg ball that is moving at 32 m/s. With what forward velocity must the goalkeeper jump when she catches the ball so that the goalkeeper and the ball have a horizontal velocity of zero?

43. In billiards, the 0.165 kg cue ball is hit toward the 0.155 kg eight ball, which is stationary. The cue ball travels at 6.2 m/s forward and, after impact, rolls away at an angle of 40.0˚ counterclockwise from its initial direction, with a velocity of 3.7 m/s. What are the velocity and direction of the eight ball?

44. Consider a nuclear reaction in which a neutron travelling 1.0×10^7 m/s in the $+x$ direction collides with a proton travelling 5.0×10^6 m/s in the $+y$ direction. They combine at impact to form a new particle called a "deuteron." What is the magnitude and direction of the deuteron velocity? Assume for simplicity that the proton and neutron have the same mass.

45. A ball of mass m_1 strikes a stationary ball of mass m_2 in a head-on, elastic collision.

(a) Show that the final velocities of the two balls have the form

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2} v_1 \qquad v_2' = \frac{2m_1}{m_1 + m_2} v_1$$

(b) Examine three cases for the masses

$$m_1 <<< m_2 \qquad m_1 \cong m_2 \qquad m_1 >>> m_2$$

(c) Comment on the results.

46. In a demonstration, two identical 0.0520 kg golf balls collide head on. If the initial velocity of one ball is 1.25 m/s[N] and the other is 0.860 m/s[S], what is the final velocity of each ball?

47. A 750 g red ball travelling 0.30 m/s[E] approaches a 550 g blue ball travelling 0.50 m/s[W]. They suffer a glancing collision. The red ball moves away at 0.15 m/s[E30.0˚S] and the blue ball moves away in a north-westerly direction.

(a) What is the final velocity of the blue ball?

(b) What percentage of the total kinetic energy is lost in the collision?

48. You and a colleague are on a spacewalk, repairing your spacecraft that has stalled in deep space. Your 60.0 kg colleague, initially at rest, asks you to throw her a hammer, which has a mass of 3.0 kg. You throw it to her with a velocity of 4.5 m/s[forward].

(a) What is her velocity after catching the hammer?

(b) What impulse does the hammer exert on her?

(c) What percentage of kinetic energy is lost in the collision?